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## **MATES Doctoral Consortium 2014**

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### **Introduction**

The MATES doctoral consortium is meant to support PhD students working in the area of intelligent agents or multi-agent systems either in advancing the theory or in relevant application areas. It aims at connecting researchers and giving PhD students a place to present and exchange their ideas and support them in working together collaboratively. The field of intelligent agents and multi-agent systems touches many different research areas. It has attracted researchers with different backgrounds like software engineering, human-computer interaction, game theory, cognitive science, logics, and business informatics to name only a few. For young researchers who want to enter this field of research, it is helpful to get an overview of these disciplines and build up a network within the research community.

The goal of the doctoral consortium is to bring together and support young researchers with different backgrounds, who are interested in intelligent agents or multi-agent systems. We invite PhD students at all stages of their research and offer a platform for presenting and discussing their results, ideas and planned work in a highly inspiring and constructive atmosphere. Moreover, upon acceptance each PhD student will be mentored by an experienced researcher, who will provide detailed feedback and advice in order to help with their intended research. This often yields valuable external input and provides the opportunity to get in touch with different researchers from a vibrant community extending one's own personal academic network.

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# Simplified planning and control with biologically inspired mechanisms for multi-robot systems

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**Abstract.** Robotic swarm systems represent an appropriate concept for large scale and volatile problems. Instead of determining complete solutions in a composite configuration space biological-inspired computing approaches apply simple rule mechanics in a decentralised fashion creating an emergent global behaviour of a system. Because of the evolutionary character of these algorithms it is difficult to plan the system behaviour in advance. This work presents a novel concept to plan and control multi-robot systems with biologically inspired mechanisms in a more accessible and intuitive fashion.

**Keywords:** swarm intelligence, multi-robot control, biological inspiration

## 1 Introduction

Many problems, that we intend to solve by using robots, are highly dynamic and of large scale. There are many examples available for these kinds of challenging applications, like precision farming, traffic surveillance, nature conservation, or construction. Moreover, robotic systems should be able to adjust to the increasing size of the problem itself. One possible solution is the development or improvement of very complex and feature rich single robot systems. Such systems are expensive, therefore difficult to justify for general purpose in small or middle-sized companies, which would like to scale their business dynamically on the specific application. A better scalability and robust solution can be derived from nature and comprises the use of a large number of distributed simple agents, usually known as swarm [16]. Examples in nature are very efficient self-organized societies like ant colonies, fish schools or swarms of bees. Such kinds of systems are highly scalable, so it is possible to reduce or extend the number of agents on demand, replace damaged entities and adapt to the changing environment quickly. The general understanding of a swarm is based on the idea of homogeneity [16], but even so concepts of heterogeneous swarms are considered, therefore a swarm can even so consist of different specialised entities [5]

Achieving the mission goals with a large scale multi-robot system would require highly complex centralised planning. Due to the highly dynamic environ-

ment it is actually not useful to find complete solutions in a composite configuration space. Moreover, centralised complete planning has a scalability problem for large numbers of entities. Therefore, current research in swarm robotics strives for highly autonomous and decentralised systems. Hence, the goal of this work is to plan a guideline for the autonomous behaviour, where the actual planning and navigation is executed in a self-organized fashion.

Based on the natural swarm role model, biological-inspired computing approaches apply simple rule mechanics in a decentralised fashion creating an emergent global behaviour. These rules embody the guideline for the single agent autonomy and are highly computing efficient, because of their simplicity.

In order to use self-organized autonomous systems, a suitable control and planning mechanism is required. For this reason the rising challenge in the application of swarms is how to control and plan swarm systems, using which kind of control and planning. The evolutionary character of swarm algorithms has the major disadvantage of unpredictability; therefore it is necessary to design the system in trial and error fashion. *The problem addressed by this dissertation is, how to design and control simple agents which are able to generate the intended emergent behaviour.*

A solution would require appropriate top-down engineering of the swarm rule mechanics, which is executable for an end user. This end user could be a swarm system designer or a system controller in the field. In the end a solution would enable wider use in practical application and therefore foster acceptance in industry.

## **2 Related Work**

### **2.1 Planning and control**

A very common and general planning and control scenario is the motion of a group of robots, e.g. in formation, from one point to another. In general control and planning concepts can be classified into centralised and decentralised. Centralised methods are error prone in a dynamically changing environment, because they rely heavily on the communication infrastructure between the agents [2] and do not support emergent behaviour. For this reason only decentralised planning and control methods are further discussed.

Many algorithms and concepts to control a self-organizing swarm are based on the very popular artificial force law approach [9]. In the beginning it was only used for collision avoidance of a single robot, but later extended to a distributed control mechanism named social potential fields to model emergent behaviour in multi-robot systems [13]. The idea behind is to model goals, obstacles, environment influences and social dependencies with attractive and repulsive forces. High level applications of this approach include decision making of kick directions in RoboCup Simulation [12] and convoy safeguarding [6]. Other concepts are based on behaviour descriptions [1], rigid virtual structures [14] and graphs [3]. These methods are less flexible and are computationally expensive.



## 2.2 Human swarm interaction

The different existing control and planning concepts are often combined with different interaction and influence techniques, examples are the leader and follower [3] or predator [7] approach. These are further divided into systems influencing the real agents [4] or virtual agents [11]. Keeping in mind the idea of autonomy and emergence it is required to strive for the most indirect and abstract manipulation or interaction. Kolling et al. classified parameter setting interaction as such kind of interaction system [10]. In this context the system is only manipulated by changing some of its parameters in contrast to moving an agent directly by explicit movement commands.

A study in a simulated battlefield scenario explores different feedback information systems and exposes the power of the potential fields method with roles and hierarchies [6]. Unfortunately the authors do not investigate possibilities of influence from the soldiers on the robot swarm.

In fact the modelling with the biologically inspired potential fields can be generalized as a particle representation, which is also the origin of this concept, using it for computer graphics visualization of flocks, herds and schools [15]. Hastings et al. [8] presented an approach for user-friendly exploration and planning of particle effects using interactive evolutionary computation. In this work the design of particle effects is guided through an evolutionary algorithm where the end users represent the quality function. The disadvantage of this approach is that the user needs to direct the algorithms step by step, in contrast to define his expected result in advance.

## 3 Approach

Biologically inspired algorithms, like the widely used potential fields, have shown to be an appropriate choice for control, planning and manipulation of multi-robot systems. As already pointed out they have several advantages, e.g. being computationally inexpensive, linear scalable for very large systems, enabling dynamic reorganisation, like adding and removing team members and are highly adjustable to environment changes.

The general idea behind potential field algorithms consists of system modelling inspired from physical force fields and social dependencies. Further abstracted, these models describe aggregated dependencies from sensory input, like distance from an obstacle, to behaviour controlling parameters, like velocity or direction. These dependencies are expressed mathematically and are defined on trial and error testing or are the result of complex mathematical descriptions of the specific problem domain.

In order to solve the proposed challenges it is the goal of this dissertation to develop algorithms, which allow for a high level definition of a swarm application, which should be usable for a robot system operator. Finally, a high level definition has to be transferred into a biologically inspired distributed control model. *Overall it is the vision to turn around the application of swarm algorithms*

*from bottom up emergence to controlled top down emergence, thus improving the usability for practical application.*

A first step towards the vision is the development of a more general and abstract model of biological coordination strategies. At the moment it is common to use only repulsion and attraction in specific ranges to describe behaviours. This could be extended with alignment, friction, visibility, live-span or other capabilities. Further, this has to be combined with an abstract model of possible sensory input and behaviour controlling output parameters.

Second, an appropriate set of high level behaviours of swarms and its temporal dependencies has to be designed. This high level behaviour should allow for a description of the final swarm behaviour. This will be used to formulate the objective function the whole system has to achieve in the end. For this reason it is important to consider real application requirements and the end user point of view.

Furthermore, it is necessary to come up with a training environment, which facilitates to determine if a system model is able to fulfil the formulated objective function. Finally, an optimisation problem has to be solved, which contains several adjustable forces, restrictions and capabilities as well as a description of a final state. In contrast to a central and complete planning approach the result is a flexible behaviour description, in the manner of the presented concept of parameter setting interaction, instead of a fixed execution path, which has to be recalculated frequently to adjust for environmental changes. The idea is to use heuristic optimisation algorithms to calculate a solution. Hence, it is planned to use as well biologically inspired heuristics algorithms, for instance particle swarm optimization or evolutionary strategy.

The evaluation of the whole concept, visualised in figure 1, is planned to be executed in applied research projects in the field of aerial robotics with unmanned aircraft systems and in the RoboCup competition. In case of the RoboCup competition several possibilities are considered. First attempts could be tested in the soccer simulation league. If the concepts shows their potential, next steps would integrate the concept in the Standard Platform League, where the laboratory is already participating. An alternative approach could be more focused on the practical application in the rescue league, but here it could be problematic to concentrate on the multi-robot approach that is a central point to this work.

## 4 Perspective

The goal of this dissertation is to foster application of the biologically inspired swarm paradigm, because it has not been found yet acceptance in practical application. On that account a state of the art analysis has shown that it is very difficult to design a swarm system with desired characteristics. Thus, a concept was developed which will enable a controlled application of emergence in swarm systems. In order to achieve the proposed vision, different work packages have been identified and are shown below with a short description.

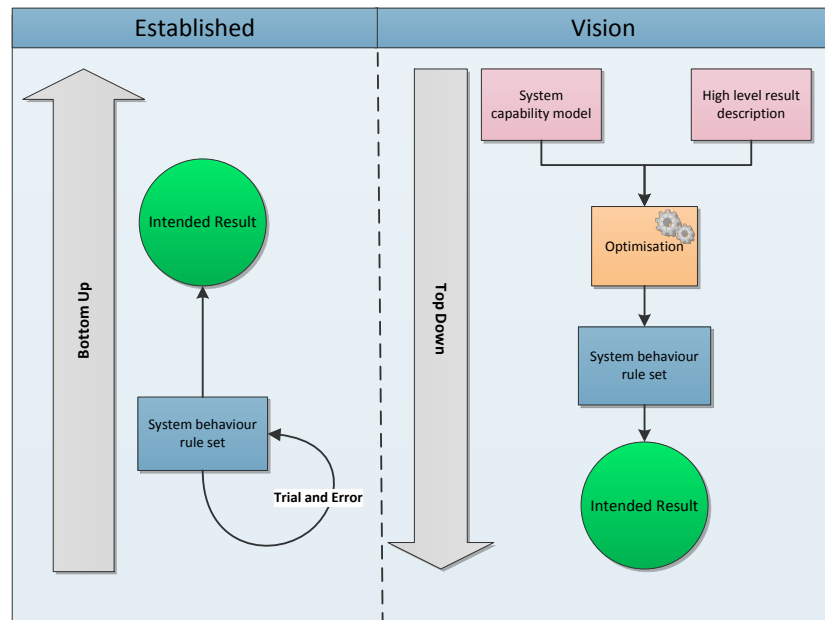


Fig. 1. Established swarm engineering vs. novel concept

**Biological forces model:** Formulation of an abstract model of biological forces, which could be used for behaviour description

**Sensory input model:** Formulation of an abstract model of sensor data to map arbitrary sensory input into the system

**Identification of high level swarm behaviour:** Identification of a suitable set of high order behaviour descriptions allowing for a wide range of behaviour definitions

**High level swarm behaviour:** Formalisation and modelling of the former identified high level behaviour set

**Abstract training environment:** Design and implementation of a training environment which combines all further developed models and formalisations

**Evaluation in practise:** Comparison to the established concept.

It is attempted to test the approach early with simple prototypes for getting first results and insights, in order to be able to modify concepts early. This will be conducted in an iterative fashion to further improve on the existing solutions.

The contribution of this dissertation will be the development of an innovative method of swarm behaviour design and control, which will boost the acceptance of biological computation and emergence in swarms.

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# Intelligent Demand Response in Smart Grids

## An Agent-Based Computational Approach

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**Abstract.** Demand response (DR) is considered a key challenge for the Smart Grid. In this context, residential customers constitute a great potential in providing their flexibility to the grid. Thus, appropriate incentives for customer participation are required. To this end, a clear understanding and specification of flexibility in a market-based context is needed in the first place. In addition, continuous interaction with new market-based systems is required for residential customers to fully take advantage of new pricing structures or incentive schemes. As this may limit the complexity of the underlying market mechanisms, decision support and automation is required to hand over a certain level of control from the customer to the machine. This thesis aims to provide a framework which facilitates customer interaction with market-based environments in the context of DR by means of decision support and automation techniques. We use a multi-agent system (MAS) approach to model the complex nature of the Smart Grid and to break down the complicated decision problem otherwise handled by a single customer into several smaller problems.

**Keywords:** Demand Response, Artificial Intelligence, Multi-Agent Systems, Markets, Decision Support

## 1 Motivation

With today's power systems evolving towards an increasing share of variable renewable energy (VRE) in the generation mix, i.e., wind and solar, system operators are faced with technical challenges of integrating VREs while maintaining system stability [6, 16]. Historically, system stability was ensured by centrally controlled systems with expensive overcapacity and balancing resources. However, the decentralized nature of VREs makes them less controllable and clearly only partially predictable compared to traditional generation assets [6]. Given the fundamental principle of power systems that supply must match demand at all times, a more flexible demand side is required to compensate for uncertainties in generation and to avoid high investment costs on the supply side [3, 8]. The most investigated and promising approach in this context is the implementation of DR [16]. While this approach has so far mostly been applied to energy intensive industrial customers [1], the large number of residential customers constitutes a

great potential in providing additional flexibility on the demand side [6, 8]. Novel and interdisciplinary approaches from computer science and economics addressing these challenges are required to further shape the ways in which residential customers interact with the Smart Grid. This research may prove to be of equal importance as electricity market design or electrical engineering for the smart grid as it is envisioned [12].

## 2 Related work

**Smart Grid and Demand Response.** Ramchurn et al. [8], Sioshansi [13] give an introduction to the Smart Grid and its concepts. Ramchurn et al. [8] also describe the key challenges for artificial intelligence (AI) and provide a research agenda for Smart Grid components such as electric vehicles, virtual power plants, consumers or prosumers. The objective of DR is to provide appropriate control mechanisms to reduce and/or to shift flexible demand from peak to off-peak times in order to maintain the balance of supply and demand in the electricity grid [14, 15]. DR in particular focuses on the demand side, i.e., engaging the customer to adapt his demand to the supply, especially by means of monetary incentives [1]. Literature defines DR in various ways [1, 4, 7], commonly agreeing that “DR includes all intentional electricity consumption pattern modifications by end-use customers that are intended to alter the timing, level of instantaneous demand, or total electricity consumption” [1].

**Learning in the Smart Grid.** Vytelingum et al. [17] develop learning strategies allowing agents to adapt to market prices in the context of micro-storage management. Rogers et al. [10] consider the home heating problem in the Smart Grid with the goal of optimizing the heating schedule based on learned thermal properties. Shann and Seuken [12] extend this work by incorporating customer preferences in terms of the comfort-cost trade-off into their model. They additionally present a method that tries to find the optimal time to query the customer. However, there exists no research to our knowledge on basic modeling of customer flexibility and accompanying learning algorithms in the Smart Grid.

**Market Design in the Smart Grid.** So far, little is known with respect to factors that influence customer flexibility in the first place. In order for flexibility to be part of future (local) energy markets, a clear understanding of flexibility in its entirety as well as a transaction object and part of a bidding language is required [18]. With the overall increasing application of market-based systems, Seuken [11] provide a research agenda on *Hidden Market Design*, identifying the need of reducing market interaction complexities by accounting for the customers’ cognitive cost and bounded rationality. Their proposed research agenda is highly applicable to the Smart Grid as we will see more end-users interacting with market-based systems in the Smart Grid, i.e., home energy management systems, EV charging stations, smart appliances or home heating devices.

### 3 Goal of PhD

The PhD thesis aims to extend the literature mentioned above. The goal is to develop an agent-based framework that facilitates the interaction between residential customers and market-based environments through automation and intermediation by decision support systems (DSSs).

Central research questions (see Figure 1 for an overview) are:

**RQ1 What are characteristics of residential customer flexibility and individual decisions in context of DR?**

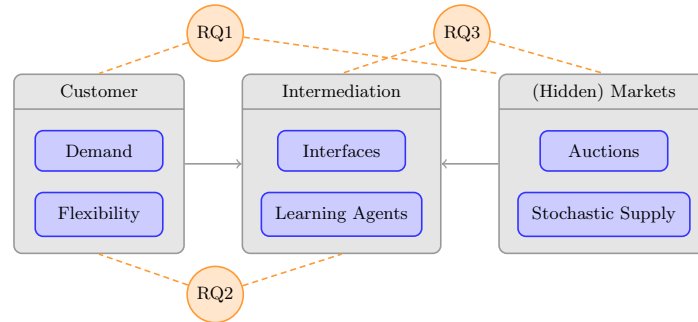
The understanding and formal specification of flexibility characteristics is the first step to building a general model that serves as basis for subsequent research questions. Modeling the decision-making problem will serve as a basis for a multi-agent-based implementation and evaluation.

**RQ2 Which machine learning methods are relevant for supporting and automating residential customer decisions and to what extend are they able to maximize individual customer utility?**

Based on the flexibility model defined in RQ1, learning algorithms should be able to determine and predict customer flexibility as well as trade flexibility in market-based environments. Additionally, algorithms need to account for non-stationary customer behavior by repeatedly querying for updated preferences.

**RQ3 What characterizes interfaces that elicit flexibility of customers and to what extend can they support market interactions?**

Given that previously defined algorithms need to continuously interact with the user, UIs should avoid information overload, display and query for information in efficient ways and support user decisions by explaining flexibility and inherently connected trade-offs. Additionally, UIs should adjust themselves to the individual users based on recent usage and other criteria. Consequently, learning algorithms should improve, achieving superior local and global outcomes for DR.



**Fig. 1.** Overview of Entities in PhD

## 4 Methodological approach

Given the interdisciplinary nature of the PhD thesis, methods from computer science as well as economics will be utilized as follows.

First, I will assess the criteria necessary to describe customer flexibility. Next, I plan to model customer flexibility in an agent-based environment. Using a bottom-up approach, this entails defining individual agents on the device level and aggregator agents on the household level. Within this MAS, the defined model for flexibility will serve as basis for an agents' goal specification as well as action space. The architecture of the MAS comprises several other roles, such as the distribution system operator (DSO), customer aggregators that operate with combined flexibilities of multiple households as well as market-related roles such as the auctioneer. Having modeled individual components of the MAS, the interaction between the agents allows for the implementation of several different regulatory regimes in which customers will have to operate. Subsequently, customer agents will be extended with learning capabilities from the field of machine learning. The plan is to use supervised learning methods as the actions are usually known to the algorithm. In particular, a possible use could be Markov decision process (MDP), which can explicitly account for uncertainties in customer behavior. The environment of the MAS will contain a market with supply from VREs. In this competitive setting, I will evaluate scenarios with and without intelligent agents, different learning strategies, population sizes and shares and compositions of VREs. Finally, I will design and empirically evaluate different UIs which capture flexibility decisions in an online context using Amazon Mechanical Turk [2, 5]. Planned scenarios include energy management in households and EVs, i.e., charging stations or in-car interfaces.

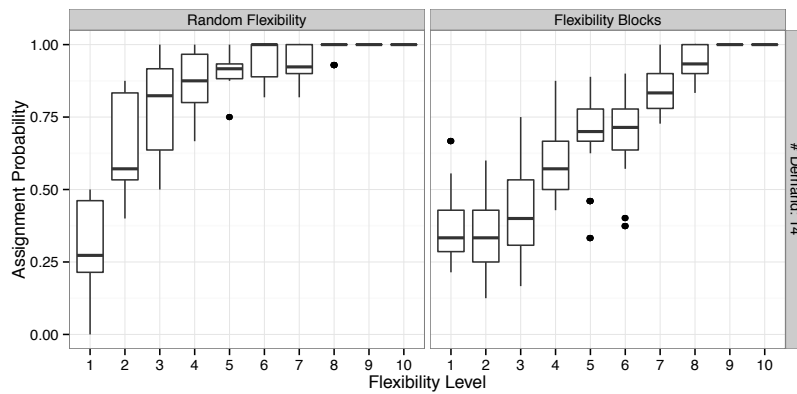
## 5 Current state

Current approaches of modeling demand flexibility are often limited in the way that they examine individual decisions of *how long* the time interval in which demand can be shifted should be [9]. This implies a continuous character of flexibility, i.e., every second, minute or time period in general can be considered an alternative in the customers' choice set. However, the number of alternatives in the choice set is usually more restricted. In particular, the customer is generally faced with the decision of *which* times are appropriate to shift his entire consumption to. This suggests that a customers' decision on flexibility is of discrete nature. In addition, the customers' decision-making process is limited by behavioral constraints, such as daily routines or the adaption to unforeseen environmental changes. We use MAS to be able to capture the complexity of the many actors and interconnected processes in Smart Grid environments

Let flexibility level  $f_{c,a}^l \in \mathbb{N}$  of customer  $cs$  agent  $a$  describe the size of the choice set, i.e., the number of available alternatives to shift the entire consumption to. The temporal structure of the consumption alternatives is given by the flexibility pattern  $f_{c,a}^p : g(f_{c,a}^l)$ . Specifically, a pattern describes the availability to consume



during time period  $T$ . The flexibility level serves as basis for a customers' choice set for the flexibility of a single device. The following figure shows the average allocation probability of an agent population in a competitive scenario. Supply is based on a real-world solar profile, the agents' flexibility pattern is random, i.e., any time-slot can be selected, and blocks, i.e., consumption limited to consecutive time-slots according to the flexibility level. For the random pattern, we can see a constantly decreasing marginal value of flexibility. For block flexibility however, the number of choices is complementary in the beginning. Therefore, it is adequate to only state limited flexibility in a random scenario whereas it is more efficient to be more flexible given a restricted pattern.



**Fig. 2.** Exemplary Simulation Result

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# Enhancing an Agent-based Test Case Prioritization System by Event Evaluation

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**Abstract.** Test case prioritization systems are useful tools to support test managers in planning test runs in regression testing. These systems evaluate information about test cases to find the best order for the test case execution. During a system's life cycle, a lot of test runs are usually performed. To give optimal support and to improve the results from test run to test run, the prioritization systems need to react dynamically to events, which occur during the different phases *development*, *test* and *operation* of the life cycle. They have to consider changes, unexpected faults found during operation, and many other events. This article describes an agent-based approach to improve a test case prioritization system by considering dynamic events for the test plan generation.

**Keywords:** test case prioritization, software agents, event evaluation

## 1 Motivation and State of the Art

Developing systems with a high quality is an important factor to succeed in the market. The high competition leads to a decreasing time-to-market and therefore to the need for efficient development and test processes. One of the major parts of the test process is the system test. It is essential to prove the compliance of the system with the quality requirements. The system test planning, specification, execution and evaluation is usually a process, which accompanies the whole development process and cannot be considered isolated. The system test is embedded in the system's life cycle. During its whole lifetime, a system is usually changed and modified to adapt to new requirements and boundary conditions. Modifications of the system are always threaten to introduce faults to the system. Even fault-free modifications can reveal faults that were already inside the system. To minimize this risk of introducing faults, the system needs to be retested after modifications. For this purpose already available test cases can be reused and executed again. The test strategy of repeating already available test cases is called regression test. Over time, the test suites, which contain the test cases for regression testing can grow to very large repositories with thousands of test cases. Executing all the test cases takes a vast amount of time and resources, which are often not available. Especially for minor changes, the

execution of the whole test suite is not suitable. Instead a selective testing of the modified system parts and components is needed.

Test planners have to identify suitable test cases to ensure that the quality of the system is not affected by faults, which were introduced with changes. They have to pick test cases out of the available test suite or define new test cases if the already available test cases are not sufficient. In order to address these challenges, test case selection and prioritization techniques are used by support systems to find the most important test cases for the available execution time. Test case selection techniques reduce the test suites by identifying only relevant test cases, for example based on changes of the source code. An overview of different test selection techniques can be found in [3] and [14]. Prioritization techniques go one step further and order the test cases by their expected benefit for the test. Unlike test case selection, a test run that is executed on the basis of prioritized test cases may be interrupted at any time having still the maximal benefit possible by the interruption time. Every test case prioritization technique can also be seen as a selection technique by skipping test cases that have a lower priority than a predefined threshold value. Test case prioritization techniques are described in [2] and [5].

The techniques can be categorized by the data they evaluate to generate the priorities. Many of the techniques proposed in the literature are based on white-box information. They analyze the source code directly to optimize the coverage of changes, e.g. in [13]. Prerequisite for these techniques is the direct access to the source code and its different versions. Due to the distribution of different development tasks to different departments and the incorporation of external modules into the system, this access is not guaranteed in every case. Hence, the black-box methods have been proposed. They use data from the test itself like execution and fault histories of test cases to prioritize them, e.g. [11]. Some techniques especially concentrate on information about requirements, identifying them as the most important entities for the test case prioritization, e.g. [12].

Some approaches have been proposed to adapt the prioritization to the ongoing test process. In [4] a prioritization technique is proposed that adapts immediately to test case results as soon as they are available. In contrast to other prioritization techniques, the test plan can be modified dynamically after every test case execution if the test results necessitate the change of the test plan. In [6] a history-based technique is proposed, which considers differences in the significance of historical data from different test runs. Younger data gets a higher weight when determining the priority. In [10] the incorporation of human factors of the developers is proposed. Their performance is tracked over time and used to find a better test case prioritization.

Those techniques are well-suited to optimize the usage of the knowledge, which is contained within the historical database. Based on that data, the proposed techniques are able to generate a very good test plan. However, the techniques are limited to the evaluation of the data that is stored during testing. To generate a optimal test run, other factors need to be considered, too. Dynamic events like the unexpected occurrence of faults at the customer's site or spon-

taneous changes of requirements, lead to the necessity to adapt the test plan accordingly. Currently, these adaptations are done by test managers based on their experience. In the underlying PhD work, I propose an agent-based test management support system, which is able to react to such dynamic events. By drawing conclusions from events, test plan adaptations are performed to relieve the test manager. Therefore the system will be able to provide better support than state of the art systems.

## 2 Basis: Agent-based Test Case Prioritization

In a preliminary work done by Malz et al. an agent-based test case prioritization system has been developed, which generates a test plan considering test case priorities and test resource utilization [7], [8], [9]. The prioritization is performed in four steps:

Malz et al. recognized the problem of test case prioritization as a distributed problem: Parts of the system, e.g. components and modules need to be tested. They compete for as much test effort as possible for them. On the other hand, the test cases, which provide those tests, compete for test resources, which are necessary to execute them. They decided to model their test case prioritization problem as a multi-agent system and established agents representing software components and agents representing test cases. Additionally the system uses interface agents to gather needed data. The following steps are performed by the agents:

**Step 1: Gather Data** – Each interface agent is responsible for one data source. Data sources can be test support tools and databases that store relevant test data. The agents use interfaces, which are provided by the linked tools or use a direct database connection. Therefore they need knowledge about the stored data and about the data structures.

**Step 2: Approximate components' fault pronenesses** – Each system component is represented by an agent called *Component Agent*. This agent holds the information about its component, which have been delivered by the interface agents in step 1. With this information and a special knowledge base, it determines a value for the expected fault proneness of the component. The rule-base is described in [9].

**Step 3: Approximate test cases' fault finding probabilities** – After the fault pronenesses of the component has been determined, test cases are searched that are suited to test especially the fault-prone components. Therefore each test case is represented by a dedicated agent called *test case agent*. The test case agent calculates the fault finding probability of its test case for each component. For the estimation of the fault finding probabilities, tester-given rules are used as well.

**Step 4: Calculate test case priorities** – In the final step, the previously calculated values for the fault proneness of components and the fault finding probabilities of test cases are combined to a priority value for the test cases. The more components with a high fault-proneness are well tested by a test case, the higher raises its priority. The priority is calculated as the mean value of a test case's fault finding probability weighted with the corresponding fault-proneness values of the covered components.

### **3 New Approach: Adding Response to Dynamic Events**

The approach presented here has the goal to extend the agent-based test management system with the capability to react to dynamic events, which occur during the development of a system. The system has three possibilities to react to such events:

**Modifying or amending data** – If the system recognizes that the data it is evaluating is wrong, or if an event brings new findings, which are not contained in the data yet, the system can modify the stored data directly. Especially user-given values like complexity and criticality approximations can be verified in later development stages when more empiric data is available.

**Adapting or reparameterizing the prioritization algorithm** – Long term changes or slight deviations in the system require a long-term adaptation of the prioritization. Therefore the prioritization algorithm is adapted itself. Parameters used for calculations or rules used for direct inferring can be changed if necessary.

**Modifying the resulting test plan directly** – Serious events may require an immediate change of the test plan as an adequate reaction. This immediate change cannot be achieved by modifying the data or by adapting the prioritization algorithm in a long-term evolution step. Rather, a direct intervention in the test plan itself is needed. S

#### **3.1 Dynamic Events During a System's Life Cycle**

This section describes the events, the agent system has to react to. Events are classified into three categories: Events from the Development, events from the test and events from the system in use.

**Events from development** Events from development are triggered during the development process - either while adding new features to the system or while correcting faults that have been found in a preceding test run.

- Source code change to fix a fault

- Source code modification to fix a recurred fault
- Source code modification to implement a new requirement
- New test case available

**Events from test** Events from test are triggered during the test phase. Usually a test phase starts after a development phase to get sure that the changes from the development phase didn't introduced faults to the system. Events from test can refer to those from the development. So, an event history with an appropriate assessment is needed.

- Test case executed
- Test run completed

**Events from operation** Events from system in operation are usually triggered by a customer's input. Since those events occur at the customer's site, they are the most critical ones. They usually need a fast reaction.

- Fault reported by customer
- Requirements changed
- Requirements' importance changed

### 3.2 Adding event-evaluation to the agents

To add the capability of reacting to dynamic events, the agents firstly need to recognize the events. After an event is recognized, the agents need to draw the correct conclusions. Some events, like the completion of a test run, can be recognized by observing the data sources of the other test tools. As far as the results are available, the event is triggered. Other events need special interfaces or human interaction because they cannot be recognized automatically.

After the events are recognized and sent to the concerning agents, they have to decide, which of the possibilities described above they use. To recognize faults in the data sources the agents use consistency and plausibility checks and rules describing wrong parameters. The long-term evolution by modifying the prioritization algorithm with a learning algorithm has already been investigated and is described in [1]. A genetic algorithm is used to optimize the rule-weights of the rules used to calculate the fault-pronenesses of components.

The possibility to alter the test plan directly is to be investigated. A rule-based approach with learning capability is imaginable here.

## 4 Summary

During the life cycle of a system, a system test is performed periodically. To maximize the test efficiency in the available test time, an state of the art agent-based test case prioritization systems is used, which order the test cases due to their performance. Based on the prioritization, a test plan is created. To enhance

the test plan generation over the life time of the system, dynamic events need to be recognized and considered by the prioritization system. In the approach presented here, those events are recognized and evaluated by the agents in order to improve the test case prioritization over time.

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## On Realizing an *intelligent* Internet of Things using Intelligent Agents

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**Abstract:** The exponential growth in the number of devices populating the Internet has propelled the research towards finding mechanisms for effectively utilizing their capabilities. These devices, which constitute a large distributed network, can be used to form an *intelligent* Internet of Things (*iIoT*) wherein intelligence could emerge as a result of interactions and collaborations among the devices. This requires a generic framework which could facilitate seamless flow of information and collaboration among the hybrid set of devices to ultimately realize an *iIoT*. Mobile agent technology provides a fitting platform to embed intelligence in such large distributed systems. The focus of this research is to develop efficient mobile agent based mechanisms to serve the purpose of building a framework which could aid in the realization of an *iIoT*.

**Keywords:** Internet of Things, Mobile Agent, Distributed Intelligence, Stigmergy, Decentralized control

### 1. INTRODUCTION

With the Internet now ready to be populated by over several billions of devices, the need for a framework that can make the best use of each of them is a hot area of research. In the current age we are surrounded by a large and heterogeneous collection of smart devices and systems. People working in the area of Cyber-physical systems, Internet of Things and M2M communications have been striving to make these devices smarter. State-of-the art *Internet of Things* (IoT) concentrate more on RFIDs, sensors, sensor webs and robots. Most portray an IoT as a centralized control mechanism to realize smart buildings, homes, water distribution and load distribution systems. Researchers working in the area of smart buildings, power grids, etc. have been focusing on how control of a complete building system or the power grid can be achieved using a centralized control mechanism that uses sensors on-board the physical interfaces and equipments. But a framework, where these devices can talk to each other autonomously and also learn from one another is still to be formulated. The objective of this research is to design a framework wherein devices can interact with one another and exhibit intelligent collaborative behaviours by utilizing a hybrid model of biologically inspired algorithms and conventional paradigms. Such a framework for an *intelligent* Internet of Things (*iIoT*) can allow both programmers and users to write programs that suit their needs and exploit the presence of these networked devices. This research aims at designing and implementing a workable framework for an *iIoT* based on distributed bio-inspired mechanisms.

Of late quite some research has been carried out that focuses on copying algorithms that exist in nature— either singularly or as swarms. They have been found to be largely effective in achieving distributed control with an underlying *stigmergic* means of communication. *Stigmergy* allows for lower level cross talks between organisms and facilitates communication by making changes in the environment in which these living beings inhabit. In the networked and computational world such a concept has been known to reduce bandwidth requirements [1, 2]. Since an *iIoT* may be looked upon as a congregation of networked gadgets, appliances or mobile/stationary devices, communication amongst them can assist in making them jointly achieve a common goal. A fast method of communication and dynamic movement of assisting programs has been cited in [3] using mobile agents and pheromones. If devices can have the ability to communicate autonomously and also exchange information (data and also programs) with other devices in their proximity and respond to the queries from other devices or assist one another, they can form a sub-system in their own environment and can exhibit smart and intelligent behaviours. Realizing such a framework requires various aspects to be looked upon:

- The communication framework needs to be robust, flexible and distributed.

- Efficient mechanisms for traversal (or migration) of information from one device to another device – on-demand or otherwise.
- Efficient strategies to service these devices.
- Mechanisms for co-operative learning and adaptation.
- Easy to use interfaces for devices and human interactions.

The use of a mobile agent based architecture such as the one described in [4] could provide a promising solution for serving as a communication framework for devices forming an IoT. The goal of this research is thus to evolve and formalize a mobile agent based framework for realizing an intelligent IoT which is scalable, efficient and has a distributed learning mechanism. Devices populating this *IoT* will communicate with each other, transfer not only data but also efficient programs and thus evolve over a period of time autonomously. Devices could include computers and laptops, appliances, wireless sensor nodes, smart phones and mobile and stationary robots. The framework will allow each of these devices to autonomously participate in achieving the goals for which the *IoT* is designed.

## 2. MAJOR CHALLENGES

The broad objective of this research is to realize a *Mobile Agent based Framework* for a *Bio-inspired Intelligent Internet of Things* wherein mobile agents carrying information will aid in servicing the *Things* (devices) and also in adapting and evolving intelligence within the network. This research aims at formalizing a viable framework for realizing an *intelligent IoT (IoT)* using mobile agents. Some of the major research challenges that need to be addressed in the realization of the *IoT* include:

1. **Realizing a generic architecture for a heterogeneous IoT:** An *IoT* may involve a variety of devices, appliances, robots and a host of other inter-connected devices. Communication and co-operation between them is thus paramount when one needs to make the best use of these entities populating the network. It is thus necessary to develop a framework to provide an appropriate layer of abstraction that can hide the differences among the entities and act as a coherent interface.
2. **Efficient mechanisms for servicing devices and information transfer:** Various devices, including robots comprising the network may require a service to be effected at a certain node in the network. This calls for autonomous mechanisms to find which device needs which service and then subsequently attract the relevant mobile agent that carries the requested service as its payload, towards the requesting device/node.
3. **Self-adaptation:** Intelligence entails that the programs carried by the mobile agents as their payloads need to be adaptive. Adaptive programs and their deployment could enable devices populating the *IoT* to adapt and reconfigure, either at the hardware or software level, based on the environmental conditions and constraints. Inter-agent communication, a distributed learning algorithm, synchronization and self-healing become key issues to be tackled for the same.
4. **Service times and bandwidth management:** The use of devices such as robots often involves computationally intensive processing such as that encountered in vision, mapping and navigation, etc. In an *IoT* comprising the robots among other devices, data/information to be processed could be shared over the network making resource and bandwidth management a vital task. Service times can be hastened by increasing the number of agents that carry the service, using cloning. This calls for a mechanism for controlled cloning of mobile agents lest they eat up a majority of the bandwidth, thus choking the network.
5. **Scalability:** Scalability is a key issue in such systems. A facility to easily add different types of devices to the network is essential.
6. **Security:** With the network acting as the main means of communication and interaction between the entities populating the *IoT*, security is a vital issue and needs to be addressed.
7. **Autonomy:** Embedding autonomy can allow for scheduling parallel and sequential tasks in such systems. It can also facilitate the searching of free resources/devices available on the network that can execute a given task. Further such *IoT*s need to have a mechanism to express a device's willingness to engage in the execution of a scheduled task on the network.
8. **Distributed Intelligence:** The network of devices should be able to adapt to their environment. They need to interact with one-another, exchange information, request for a service, provide a service, etc. If the participation of a set of devices is needed to achieve a goal, then this set may need to work in synchronism. In case of a decentralized IoT a mechanism for synchronization across the network may need to be addressed.

### 3. SIGNIFICANCE

The Internet of Things (IoT) is a comparatively new area of research and most of the related work has been confined to the control of RFIDs, wireless sensor nodes or sensor webs. The work reported in literature seems more towards a centralized control strategy where a plan of action is already in place and the system senses and takes decisions based on a set of sensors and actuators all of which are interconnected in some manner. Researchers have been working on sensor networks [5], M2M devices [6] and the Internet of Things [7] for almost a decade. Several algorithms for adaptive [8, 9], collaborative and decentralized control, group behaviours [10], etc., have been proposed. Research has also focused on using Information and Communication Technology (ICT) for evolving smart cities, smart buildings, smart power-grids, etc. Of late new concepts in networking have provided greatly towards ubiquitous environments [11]. The ubiquitous cell phones can now be used for controlling appliances such as air-conditioners, televisions, etc. There is yet a need to standardize such utilities to allow the same to be extended to a range of appliances. Intel has been a forerunner in identifying the potential of an IoT and has heavily invested in its research. With sensory devices on the verge of becoming ubiquitous and with a view to take on research in the Internet of Things, Intel has released its low-power Atom processor for mobile devices [12]. This processor supports basic computing as well as network access and comes in both single and dual core packages with the best in-class capabilities, support for Windows and Linux and excellent energy saving features resulting in a longer battery life. Intel has proposed the use of this processor in treadmills, home based appliances and many gadgets for medical use. It has identified the need for device to device communication in a variety of areas such as factories involving complex manufacturing stages, sensor networks on railroads, smart roads, smart lights, smart shopping, etc. and in many ways suggested the imminent era of the IoT. IBM [13] has a major stake in this area having around 2000 projects under their smarter planet vision. Other corporate companies are also competing in this area to drive the concept of green IT and green infrastructure. TCS Innovation Lab., Kolkata is developing a framework nicknamed RIPSAC for Cyber Physical Systems which will eventually allow developers to deploy their applications directly over a sensor web or M2M device networks. Apart from sensors and appliances, the area of IoT has also spilled gradually to include robots [14]. In most of the applications that have been cited, the IoT requires a supervisory control on the whole setup. A distributed and decentralized mechanism for adaptation of a device to the networked environment is however grossly missing. Mobility of the devices has also not been addressed. Autonomy and intelligence have been side-tracked in the sense that the human controller seems to be always in the loop and a sort of centralized program, embedded *a priori*, controls the operations of the IoT.

Mobile agents are ideally suited to embed both autonomy and intelligence in a network of things. They can autonomously sense, make decisions, learn and adapt within the network they populate. They can also provide all pertinent information *on-demand* to other entities within the network. Since mobile agents have the ability to make decisions as to which node or device to migrate and carry which payload (a set of programs) together with their state, they form the best tools to embed and exhibit distributed and intelligent control over a network. There have been several scenarios where such agents have been used effectively. Cragg and Hu [15, 16] elaborate on how mobile agents augment robots to create an ALLIANCE like distributed computing system. They have proposed and used a multi-robot system along with mobile agents to form patterns of robots. These robots can share knowledge and information to achieve complex tasks. Kambayashi *et al.* [17] have also used mobile agents on multi-robot systems to perform experiments including control of biped walking. The same author has also used a mobile agent approach for an interesting trolley collector problem in an airport [18]. Godfrey and Nair [2] have devised effective bio-inspired mechanisms for migration of mobile agents for use in networked robots and devices. Their studies have clearly shown how mobile agents can play a highly pro-active role in realizing an Internet of Things [19].

Realizing an *IoT* will allow a large set of users to make use of the vast resources made available by an almost equally large and heterogeneous set of devices populating the network. But the *IoT* is still in its conceptual stage with no formal framework to create or maintain it. The initial investigations and work carried out by Godfrey and Nair [2] have clearly shown that the use of mobile agents as pro-active carriers of information and programs can form the basis for the realization of an almost autonomous IoT with little or no human intervention. They have used a pro-active bi-directional search that uses pheromone diffusion coupled with a conscientious approach for efficient mobile agent migration within the network. Such a search allows the mobile agents carrying the relevant service (programs) to reach the requestor (node or device) at a faster pace culminating in a quicker service. Though these mobile agents also exhibit controlled cloning [20] to facilitate a still quicker and parallel service at various nodes (devices) requesting their service (program), their payloads still remain static. For a system to perform well, an inherent learning mechanism needs to be embedded. Coupled with agents moving across the network using efficient search strategies and with the services (programs) evolving with time, the *IoT* is bound to perform more efficiently and autonomously with minimal human intervention. The applications of such an *IoT* are obviously immense. In a hospital scenario, for

instance, such a framework can cause an automated stretcher/wheelchair (device) to search and find the patient who requested its service. Mobile agents could also trigger a search for a doctor with the relevant specialization and inform him/her of the status of the patient pro-actively. In a manufacturing zone, such agents could move around across devices to monitor the state of sub-systems, trigger alarms, activate or deactivate switches and even find and guide robot/human users capable of rectifying the fault to the exact location. If the programs being carried by agents as payload were capable of learning and evolving, a swarm of robots could, by executing them and thus getting feedback from the real world, churn better and efficient programs from the available naïve ones.

#### **4. OBJECTIVES**

The **iIoT** framework calls for research to be carried out in variety of domains. These can be broadly categorized as three major areas - (i) improving base level technologies e.g. wireless communications, sensors etc. (ii) developing standard interfaces and (iii) creating efficient control mechanisms. The focus of this research is towards evolving intelligent control mechanisms to service the **iIoT**. As pointed out earlier, this research uses mobile agent technology as means to realize the intelligence within an IoT. Hence, the prime focus is towards developing mobile agent based mechanisms for a network of nodes (devices). The nodes here make up the environment which is inhabited by the mobile agents. These nodes may request or require a variety of services that need to be fulfilled by the mobile agents which acts as the providers of the services. By services, we mean a program or code that needs to be executed at a node or some information that is required at a node. These mobile agents can be considered as individual of a swarm wherein their local interactions at the micro level could be used to realize a larger goal at the macro level within the environment. Following are the concrete problems whose solutions form the major contributions of this research:

1. **Mechanism to control population of heterogeneous mobile agents:** In the envisaged **iIoT**, mobile agent serves as the means of information transfer and provides various services. Heterogeneous mobile agents mean the groups of mobile agents carrying different services. The size of these groups or the population of mobile agents for specified services needs to be carefully managed within the network of nodes. An unmanaged population could clutter the network and create delays for other services. Further, the population of mobile agents should vary based on their current demand within the network. The population of a mobile agent whose service is required by a large number of nodes should grow while the population of others which are less required should diminish. This has to be done in a distributed manner with minimal overheads. In this research, a stigmergy based mechanism to control the population of heterogeneous mobile agents has been proposed [21].
2. **Mechanism to evolve mobile agents carrying better services:** Since mobile agents are responsible to provide services to the nodes, one can have different mobile agents providing different solutions for a single service. For example, mobile agents carrying different algorithms to service a request of finding a path to a destination node in a network. The **iIoT** could be regarded as intelligent if the mobile agent carrying the best solution could emerge from the group of mobile agents and dominate the population of mobile agents within the network. Hence, the users can release new services or solutions into the network on the fly which would automatically replace the less optimized solutions without any external interruption. This research proposes to develop such a solution by taking inspirations from the models of Artificial Immune Systems wherein the service requests are regarded as antigens while the mobile agents capable of providing solution for a service acts as antibodies [22].
3. **Mechanism for coordination of activities among mobile agents:** The population of mobile agents within the **iIoT** can provide for the parallel and concurrent execution of tasks at different nodes in the network. In this context, the mobile agents can act as individuals of a swarm or insect colony to coordinate their local activities for achieving a higher level goal. The coordination of activities could be based on their interactions with the local environment (nodes here) and with one-another. Further, such a mechanism could enrich the **iIoT** to show intelligent behaviour by coordinating the activities among various nodes. The concurrent execution of tasks could also aid in achieving faster responses in lesser time. One critical aspect of developing such a mechanism is that it should be distributed. This research endeavours to propose such a distributed mechanism based on the concepts of *stigmergy* for coordinating parallel and concurrent execution of a sequence of tasks in a network of nodes [23].
4. **Mechanism for learning and sharing of information among mobile agents:** Learning and sharing of information are crucial aspects of any evolving system. One cannot realize the enterprise of an **iIoT** without embedding the methods of adaptation, learning and information sharing among the mobile agents within **iIoT**. One of the characteristics of mobile agents is their capability to migrate within the network.

Such a capability could be exploited to collect information scattered within the environment and use that information to learn and evolve. Mobile agents can further share their information locally by interacting with each other and help to improve the knowledge of the population as a whole. With these mechanisms, the *iIoT* can autonomously evolve solutions of some problems which may be dynamic in nature. Further, the learning could be regarded as a continuous process which would keep on optimizing the *iIoT* as per the prevalent conditions within the environment. This research puts an effort to formulate a distributed mechanism to regulate the information sharing and learning among the mobile agents within the envisaged *iIoT*.

The end result of this research is to realize all the above mentioned mechanisms in conjunction with one-another for specific application domains. These application domains would act as platforms to realize *iIoT*. The envisaged *iIoT* framework will thus use these mechanisms to facilitate efficient migration of mobile agents and hence information and programs as their payloads to individual devices populating the network. These would empower the devices and entities populating the network to communicate, share and co-exist within the network while at the same time assist each device in achieving its goal. Further this would allow novice users to tether and make use of the network. Since the flow of mobile agents within the network can cause the transport of programs on-demand to a device, novice users will be in a position to tether their devices onto the network in spite of their low programming skills. The work carried out by Godfrey and Nair [3] provides proof of concept for this aspect. The programs being circulated within the network will learn, evolve and adapt to make the IoT intelligent. Mobile agents carrying programs will communicate and evaluate the best programs in a distributed manner and shed ones which are less efficient. Controlled population [21] of mobile agents carrying the more efficient and more needed programs will facilitate faster services across the network.

## 5. APPLICATIONS

Realization of such a framework for an *iIoT* will not just allow agents to pro-actively aid users with their individual tasks but will also serve to form ideal real-world test-beds for research in distributed and asynchronous swarm behaviours. A set of sensors, devices and robots constituting an *iIoT* can be looked upon as a connected swarm wherein the individual nodes may not be as intelligent as the swarm. As this research emphasizes the development of a framework to connect a gamut of devices, various applications of the same can be thought of. Following is a non-exhaustive list of some of the application scenarios wherein the framework can prove to be useful:

- **Economizing power:** With such a framework in place, electric power could be utilized in a more efficient way. Mobile agents could patrol through various gadgets/devices within a campus/building and monitor and switch on/off lights or other devices within. They could also intelligently and autonomously schedule such switching based on high/low power peak periods and even learn to optimize power.
- **Non-intrusive information search:** Mobile agents can also perform searches for specific information within the devices/nodes they migrate to. Such searches could be performed without the device owner's participation (provided the user has shared such information). For instance in a conference or congregation such mobile agents could be spawned and sent around to detect the presence or absence of a certain person (using a certain device), find his/her bearings (using the GPS on the person's device) and also find more information from the shared profile within the device (such as his/her profession, interests, etc.)
- **Medical Aid:** In case of a medical emergency, a user's device could spawn an agent that could migrate to devices in the vicinity and find whether the owner is a medical doctor and then inform and guide him/her to the patient.
- **Automatic software updates:** This framework can be used for maintaining and updating of software – especially carrying out fresh installations in a large network of devices as cited in [24].
- **Autonomous M2M scenarios:** An *iIoT* can be used to autonomously provide services for one another [25]. If a sensor node within the *iIoT* detects an issue (e.g. an obstacle or object on or in front of it), it could spawn an agent to search for a suitable device (for instance a robot) within the network which is capable of solving the problem, guide it towards the sensor node and instruct it to solve the problem at hand (viz. push the obstacle or object away). If the device/robot does not have the appropriate program to accomplish the task, a mobile agent resident within the device/robot could be made to search/attract agents carrying the required program as their payload. Execution of the program by the device/robot could thus provide the necessary assistance to recover from the problem reported by the sensor node.
- **Transactional Support:** Imagine a multi-hop network wherein the nodes are mobile devices such as mobile phones. In addition the network could also be populated by various networked appliances such as smart refrigerators, vacuum cleaners, garage doors or even robots and printers. In a co-operative and intelligent set-up each of these devices may need to not only communicate but also service the other. If  $M_i$ ,

$M_2, \dots, M_m$  designate the mobile phones and  $A_1, A_2, \dots, A_n$  the networked appliances, one may imagine a scenario where a robot  $A_1$  may require the services of a vacuum cleaner  $A_5$ . Normally if the two devices are out of each other's wireless communication range, such a service will never be realized. The network of nodes  $M_m$  can now act as intermediary nodes to facilitate a path and allow the request messages as also the services carried by mobile agents to migrate from the networked robot  $A_1$  to the networked vacuum cleaner  $A_5$ . With navigation and position information provided by the robot to the vacuum cleaner, the two can soon come within their respective wireless ranges and perform the required service.

Apart from opening up a gamut of application scenarios for the **IoT**, this research also throws more insights into new ways of embedding intelligence into large and heterogeneous networks using bio-inspired techniques. All non-intrusive and pro-active search scenarios described in [26] could also easily be incorporated.

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## Quality Assessment of Multi-Agent Systems

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**Abstract.** Although the first studies which addressed the software quality are emerged in the 1970s, this subject still one of the active fields in software engineering. In fact, the continued evolution of software paradigms prevents the direct application of existing studies in this field to actual paradigms. Specifically, we should take into account the specificities of the agent paradigm while studying the quality of the agent based software. This opinion is supported by several researchers who require new methodologies, methods and techniques to develop multi-agent systems. Consequently, we aim to study and assess the quality of multi-agent systems' applications. This paper gives an overview of our contributions which consist mainly in the development of a quality model for multi-agent systems (called QM4MAS) and the measurement of the complexity of agent based software. Moreover, we present the future works planned as part of our doctoral project.

**Keywords:** Multi-Agent Systems, Quality Models, Complexity, Measurement.

### 1 Introduction

The quality software is considered as an important research subject in the mid 1970s [1]. Since then several quality models are proposed to master the complexity and the ambiguity of the quality's concept. Considering their purposes, these quality models can be used to specify, to evaluate and/or to expect the quality of software product. On the other hand, several software paradigms are appeared since the emergence of the first quality models. The quality is a primordial requirement whatever the software paradigm. However, we should take into account the specificities of each software paradigm when we study the software quality. Thus, several works targeted

specific paradigms like object-oriented programming [2], component based software [3] or B2B applications [4].

Nowadays, multi-agent systems are considered as one of the most applied software paradigms. A multi-agent system is composed of a set of interacting entities called *agents*. Hence, it can be shown as a natural metaphor for modeling complex systems [5]. Moreover, we think that this software paradigm which appeared since about twenty years ago has reached a maturity level to address the quality of its based application.

We aim in this paper to present our research project which consists of modeling and measuring the quality of multi-agent applications. Indeed, the quality is an essential software requirement. For this reason, it is important to define the software quality's concept and to assess it because of the ubiquitous nature of software in our products nowadays. Specifically, the quality of multi-agent systems has a particular importance because of two reasons. First, the multi-agent systems are relatively new software paradigm that requires its own development methodologies, methods and tools [6]. So, we should targeted specific quality models and metrics for multi-agent systems. Second, the multi-agent systems are used in a wide range of applications from children's games to complex critical systems. Hence, we should study the quality of such systems to avoid the eventual catastrophic results of using bad quality products.

Our project addressed the following questions: Can the existing quality models be used for multi-agent applications? How we can extend the existing quality models to take into account the intrinsic characteristics of such systems? How we can measure the quality of such systems?

The remainder of this paper is organized as follow: a state of the art is presented in section 2. Section 3 is devoted to present our contributions in this subject followed by the presentation of some future works (in section 4). Finally, conclusion is presented in section 5.

## 2 State of the Art

The quality is one of the most important requirements in all the software projects. However, the study of this concept confronted two essential questions. First, *what is the quality*? In fact, it is hard difficult to specify *uniformly* the quality concept. Each one of the stakeholders (designer, programmer or user) understands the quality differently. The second question is about the specificities of the software product compared by other products. Indeed, we consider the software as a specific kind of product because of their abstract nature (it has not a form, a color nor a weight). Consequently, it seems hard to specify or measure the quality of an abstract product.

The software quality has been studied since the 1970s where the models are recognized as a good technique to specify and measure this complex concept. McCall et al. [1] proposed one of the well accepted quality models. They specify the quality in hierarchical way using factors, attributes and metrics. The factors represented the external behaviour of a system like: reliability, reusability and portability...etc. A quality factor is affected by a set of attributes that are related to software develop-

ment. For example, the modularity as an attribute of software architecture affects the reusability factor. To avoid the confusion produced by the diversity of quality models, the International Organization for Standardization (ISO) proposed the ISO/IEC 9126 quality model as a standard to define and measure the software quality [7]. Recently, a series of quality models, called SQuaRE, have been proposed as a new generation of quality models [8].

Quite a long time, the evolution of software paradigms has been considered as a motive to develop specific quality model for each paradigm. In fact, each software paradigm has its own characteristics that we should take into account during the study of its based software. Accordingly, specific quality models are proposed for each software paradigm. These quality models can be seen as an extension of conventional quality models (like the extension of the model of McCall et al. [1] to support object-oriented software [2]), as a quality models designed specifically to specific software paradigm [9] or as a customizing of the standard quality models with taking in consideration the specific characteristics of the studied software paradigm (like the use of ISO/IEC 9126 to evaluate the quality of B2B applications [4]).

We think that the agent paradigm reaches a maturity level to target the quality of agent based software. However, almost studies proposed in this field are of empirical nature. Thus, several metrics are proposed to measure some attributes of multi-agent systems like the communication [10], the complexity [11] and the architectural design [12]. An overview of these metrics is presented by Dumke et al. [13]. We think that the quality concept is a complex concept which is composed of a set of attributes. Moreover, these attributes can be in a conflicting relation (the relation between the reliability and efficiency is the typical example). Consequently, it seems important to propose an overall quality model for multi-agent systems in order to represent *all* the attributes that affect this complex concept. Alonso et al recognized this necessity and propose a series of works to model the quality of multi-agent systems [14, 15, 16]. They model the quality of multi-agent systems using six characteristics: social ability, autonomy, pro-activity, reactivity, mobility, intelligence, and adaptability [14]. Each one of these characteristics is decomposed in several attributes. For example, the autonomy is decomposed into three attributes: self-control, functional independence and evolution capability [15]. Each attribute can be empirically evaluated using a several metrics.

Despite that we share the same opinion with Alonso et al. [14]; we think that an overall quality model should specify both the high level quality characteristics of software and the specific characteristics of multi-agent systems. Indeed, the high level quality characteristics like reliability, the efficiency and the maintainability are required characteristics for any software whatever the paradigm used to develop it. So, we aim through our doctoral project to develop an overall model allowing the definition and the measurement of the quality of multi-agent systems. The next section is devoted to present our main contributions in this subject.

### 3 Contributions

The above state of the art allows us to identify the main weakness in the proposed studies for the quality of multi-agent systems. As a result, we think that the lack of an overall quality model for multi-agent systems is the main drawback. We mean by an *overall* quality model a quality model which represents both the high level quality characteristics with the specific features of multi-agent systems. Hence, our first purpose is the specification of a comprehensive quality model allowing the definition and the measurement of the quality of agent based software. Furthermore, we target the study of some attributes that affect the quality of such systems. We present in this section our main obtained results.

#### 3.1 A Quality Model for Multi-Agent Systems (QM4MAS)

Because of the noticed lack of a comprehensive quality model for multi-agent systems, we proposed a quality model for the definition and the measurement of agent-based software. The proposed quality model, called QM4MAS [17], is an extension of the standard ISO/IEC 9126. We start our study by analyzing the characteristics of the ISO/IEC 9126. So, we extend the six characteristics defined in this standard (*Functionality, Reliability, Usability, Efficiency, Maintainability and Portability*) by two important characteristics: *the flexibility and the reusability*. The reusability has been added according to Dromey [18] who remarked that this important characteristic is omitted from the ISO/IEC 9126. The flexibility reflects the intelligence behaviour of the multi-agent systems. Then, we identify the main features that are made of the multi-agent systems a new software paradigm (*the autonomy, the reactivity, the pro-activity, the interaction, the adaptability, the rationality, the specialization, the organization, the environment and the granularity*). The sub-characteristics level of the standard quality model has been extended by the identified characteristics. The characteristics are connected to the sub-characteristics by the affectation relationships. As an example, the flexibility is connected to the reactivity, the pro-activity, the adaptability and the social ability because these sub-characteristics affect the flexibility of the multi-agent systems. In the third level of the proposed model, we propose a metrics to assess each sub-characteristic. However, because of the diversity of the multi-agent platforms, these metrics are given in general statement as only abstract guidelines. Consequently, we should instantiate these abstract guidelines depending on the specific characteristics of each multi-agent platform in order to obtain concrete metrics. Our idea is validated upon JADE platform [19] and a tool is developed to automatic measure the different metrics. It seems important to note that we use the aspect programming paradigm to measure the proposed metrics. Using this paradigm, we can apply dynamic metrics in a simple way. Moreover, the metrics can be developed independently to the evaluated software.

### 3.2 Complexity Measurement of Multi-Agent Systems

The complexity of the code is an important factor to evaluate the software quality. In fact, this factor can be used to estimate the required effort to understand and maintain existing software. Known that the multi-agent systems are designed as a natural metaphor to develop complex systems, their complexity can become unmanageable. Consequently, we target the measurement of the complexity of the agent-based software in order to estimate the maintenance effort [20]. In order to propose the complexity's metrics, we start by the specification of a model for this notion. Indeed, the complexity of the multi-agent systems can be seen from two perspectives: the individual and the system levels. The individual level is decomposed into the structural and the behavioural complexities. The system level is decomposed into the social's structure and interactional complexities. Each one of these four facades is measured using a set of metrics. For example, the structural complexity is measured using the following metrics: *the Size of the Agent's Structure (SAS)*, *the Agent's Structure Granularity (ASG)* and *the Dynamicity of the Agent's Structure (DAS)* metrics. We use both the static and dynamic metrics in order to collect the proposed metrics. The static metrics are made by the analysis of the code. Contrariwise, we use the aspect programming paradigm to collect the dynamic metrics. A tool to assess automatically the complexity of JADE [19] application has been developed during this stage of our project.

### 3.3 The Use of ISO/IEC 25010 Quality Model for Multi-Agent Systems

The ISO/IEC 25010 quality model [21] is proposed as a part of SQuaRE series of standards. This latter is considered as a new generation of software quality models [8]. Compared to the ISO/IEC 9126 quality model, the new standard seems more complete because it is composed of eight characteristics: *the functional suitability, the reliability, the performance efficiency, the operability, the security, the compatibility, the maintainability and the transferability*. Marir et al. [22] remark that the diversity of the quality models can make the confusion. Thus, the application of the international standards when possible is more beneficial than the proposition of quality models for each software paradigm. The authors [22] studied the ability of using the ISO/IEC 25010 for multi-agent systems. In order to increase the applicability of the generated model, they identify only the mandatory characteristics of multi-agent systems. Based on the definition of Wooldridge [5], the main features of the multi-agent systems are: *the autonomy, the situatedness, the reactivity, the pro-activity and the social-ability*. These features are studied comparing to the sub-characteristics of the ISO/IEC 25010. As conclusion, the author remarked that some features can be expressed fully or partially using this quality model. The international standard is extended by the proactive ability, the act-ability and the perceive-ability to support the multi-agent systems.

## 4 Future Works

After the proposition of several works as a part of our doctoral works, we conclude that the diversity of the multi-agent systems platforms is a real obstacle to develop unified quality model for them. In fact, the multi-agent systems can be implemented using various software paradigms like the object-oriented programming or the knowledge-based systems. Obviously, the characteristics of these software paradigms reflected to the development of the quality model. Especially, the metrics are closely dependent to the multi-agent platforms. Consequently, we are working now into two distinguish directions to resolve this problem. First, we study the ability of applying the standard quality models to specific agent models and platforms. The second solution consists in the proposition of meta-model for the quality of the multi-agent systems. Obviously, the meta-model can be instantiated to generate specific quality model for each agent model or platform.

The first solution consists in the proposition of several extensions of the standard quality models to support the variety of agent platforms and models. We start by the study of the quality of the DIMA platform [23]. DIMA is a modular model which provides the possibility to develop various kinds of agents from reactive to adaptive ones. Hence, we propose to identify the list of agent's features supported by this platform. For each feature, we propose a set of metrics specific for this platform. In this way, we will develop a specific quality model for only DIMA agent. In the same way, we can study the other agent models (like the BDI agent) or the other agent platforms.

The second solution is based on some studies that attempt to give a framework to study the multi-agent systems. As an example, the Vowels [24] approach proposed the study of the multi-agent systems through the study of four concepts: *the Agent, the Interaction, the Environment and the Organization*. Consequently, we propose to develop a meta-model of the quality of the multi-agent systems using the Vowels approach. The quality of the multi-agent systems becomes the quality of the agents, the quality of the interaction, the quality of the environment and the quality of the organization. Each concept of these concepts should be specified independent to any model or platform. In order to apply the meta-model to a concrete example, we need just to identify the required concepts and features. For example, some platforms did not give explicitly the organization of the multi-agent systems. In this case, we will omit this concept to generate a quality model that supports only the features of the specified platform. We think that this proposition can be beneficial if the four above concepts are studied deeply and if the proposed meta-model is coupled with explicit methodological to simplify the application.

## 5 Conclusion

The quality is considered as one of most important requirement of software. Known that software is ubiquitous product, the use of bad quality software can produce catastrophic results. Although the software quality is studied since about forty years ago, the continued evolution of the software paradigms requires continued evo-

lution of the quality models. Despite that the agent paradigm is one of the most applied software paradigms nowadays; there is not an overall quality model that supports the features of this agent-based software. We aim through our doctoral project to study the quality of the multi-agent systems. We proposed in this stage of our project an extension of the ISO/IEC 9126 to support the multi-agent systems. Moreover, we study the ability of using the ISO/IEC 25010 to define the quality of the multi-agent systems. Considering the complexity as an essential concept which affects the software quality, we propose a model and a set of metrics allowing the evaluation of the complexity level of the code of the agent based software.

During our project we conclude that the proposition of the unified quality model which supports the variety of the existing agent models and platforms is hard difficult. This difficulty increased by the lack of unified definition of the agent features. So, in the actual stage of our research we work to propose specific quality model for each agent model or agent platform. As a second solution, we will work to propose a meta-model for the quality of the multi-agent systems to allow the generation of instance quality model for each agent model.

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